

Aspects of Higgs Physics at Future Colliders: The Extended Reach

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1. Motivation
2. Higgs coupling determination at the LHC
3. The heavy MSSM Higgs mass scale: indirect measurement
4. The heavy MSSM Higgs mass scale: direct measurement
5. Conclusions

1. Motivation

Problem:

Gauge fields Z, W^+, W^- are **massive**

explicite mass terms in the Lagrangian \Leftrightarrow breaking of gauge invariance

Solution: Higgs mechanism

scalar field postulated, mass terms from coupling to Higgs field

Higgs sector in the Standard Model:

$$\text{Scalar SU(2) doublet: } \Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

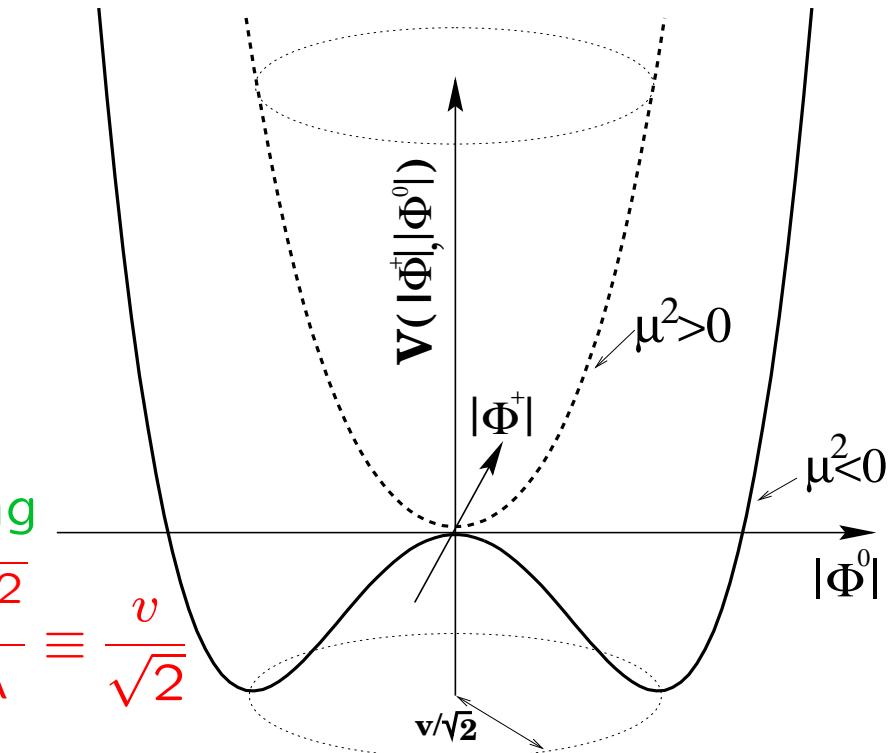
Higgs potential:

$$V(\phi) = \mu^2 |\Phi^\dagger \Phi| + \lambda |\Phi^\dagger \Phi|^2, \quad \lambda > 0$$

$\mu^2 < 0$: Spontaneous symmetry breaking

minimum of potential at

$$|\langle \Phi_0 \rangle| = \sqrt{\frac{-\mu^2}{2\lambda}} \equiv \frac{v}{\sqrt{2}}$$



$$\Phi = \begin{pmatrix} 0 \\ v + H \end{pmatrix} \quad (\text{unitary gauge})$$

H : elementary scalar field, Higgs boson

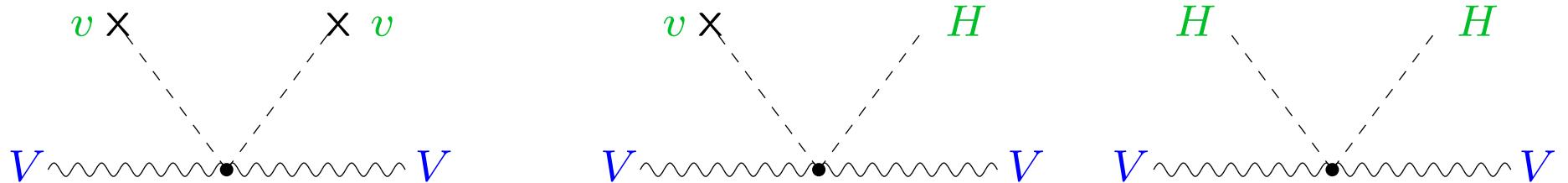
Lagrange density:

$$\mathcal{L}_{\text{Higgs}} = (D_\mu \Phi)^\dagger (D^\mu \Phi) - V(\Phi)$$

Gauge invariant coupling to gauge fields

⇒ mass terms for gauge bosons and fermions

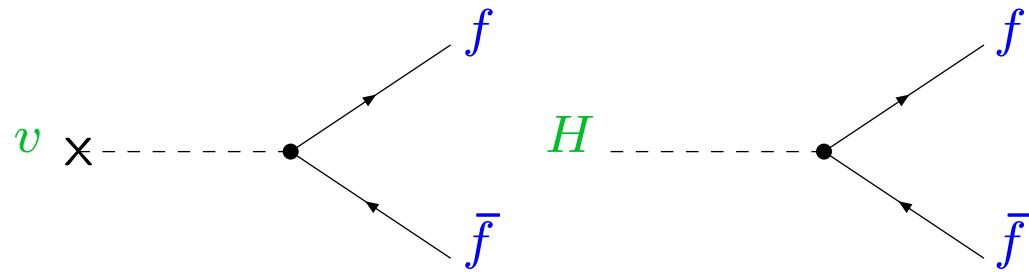
1.) $VV\Phi\Phi$ coupling:



⇒ VV mass terms

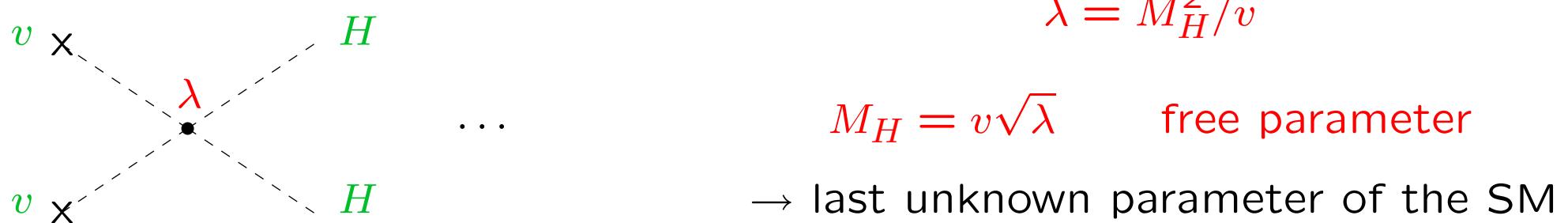
$$g_2^2 v^2 / 2 \equiv M_W^2, \quad (g_1^2 + g_2^2) v^2 / 2 \equiv M_Z^2 \Rightarrow \text{coupling} \propto \text{masses}$$

2.) fermion mass terms: Yukawa couplings



$$m_f = v g_f \Rightarrow \text{coupling} \propto \text{masses}$$

3.) mass of the Higgs boson: self coupling



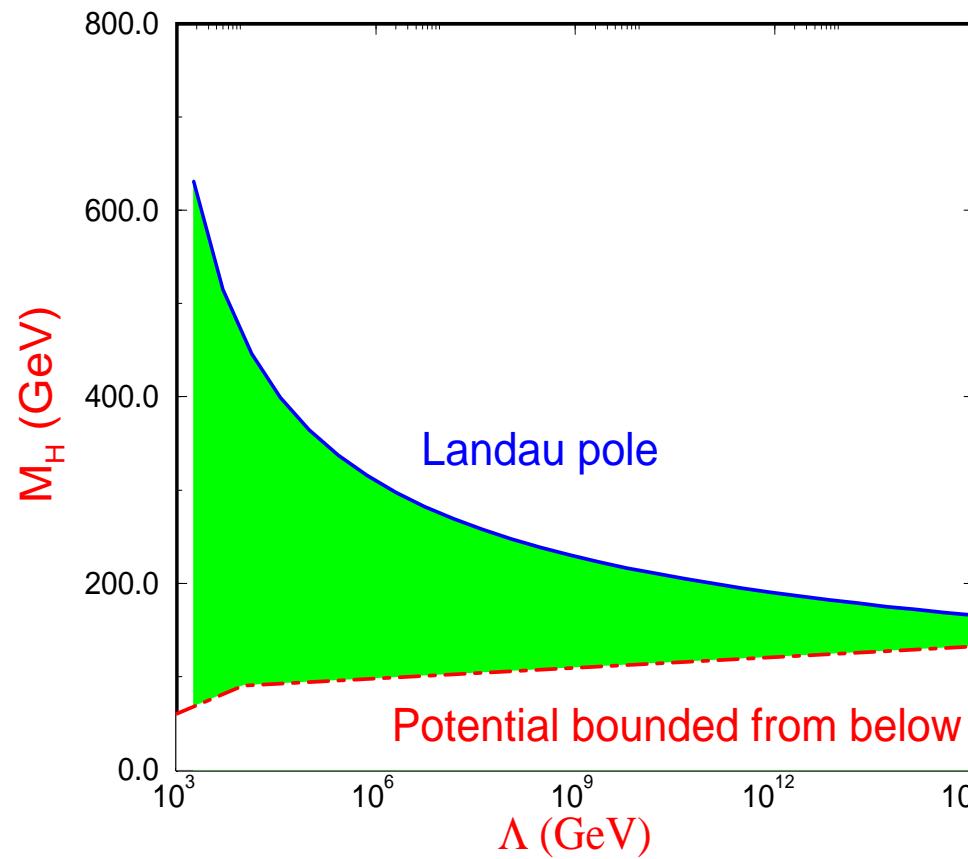
⇒ establish Higgs mechanism ≡ find the Higgs ⊕ measure its couplings

What else do we know about the Higgs boson?

SM at high energies

- upper limit on M_H :
 - dependence of coupling λ_{HHHH} from energy scale Λ
 - ⇒ divergence: Landau pole
- lower limit on M_H :
 - stability of the vacuum :
 $V(v) < V(0)$
 - [Coleman, Weinberg '73]
- combined

⇒

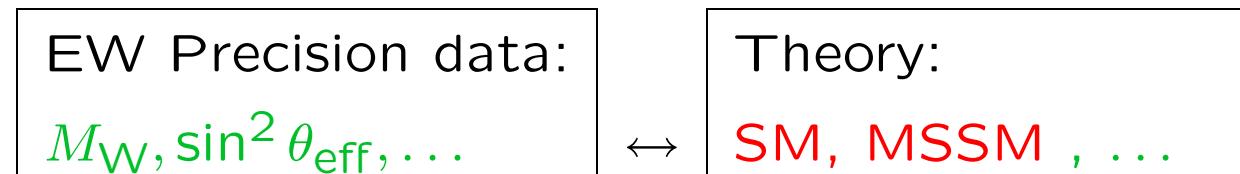


Λ : scale up to which the SM is valid

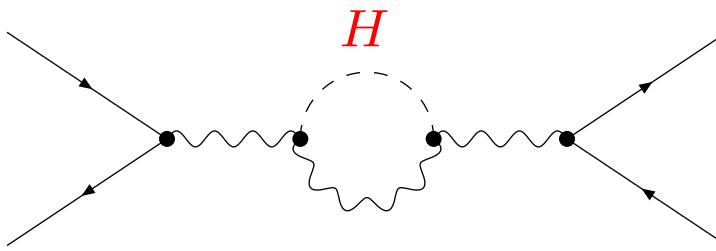
$$\Lambda = M_{\text{GUT}} \Rightarrow 130 \text{ GeV} \lesssim M_H \lesssim 180 \text{ GeV}$$

Indirect measurements via precision observables (POs):

Comparison of electro-weak precision observables with theory:



Test of theory at quantum level: **Sensitivity to loop corrections**



All parameters of the model enter
limits on M_H

Global fit to all SM data:

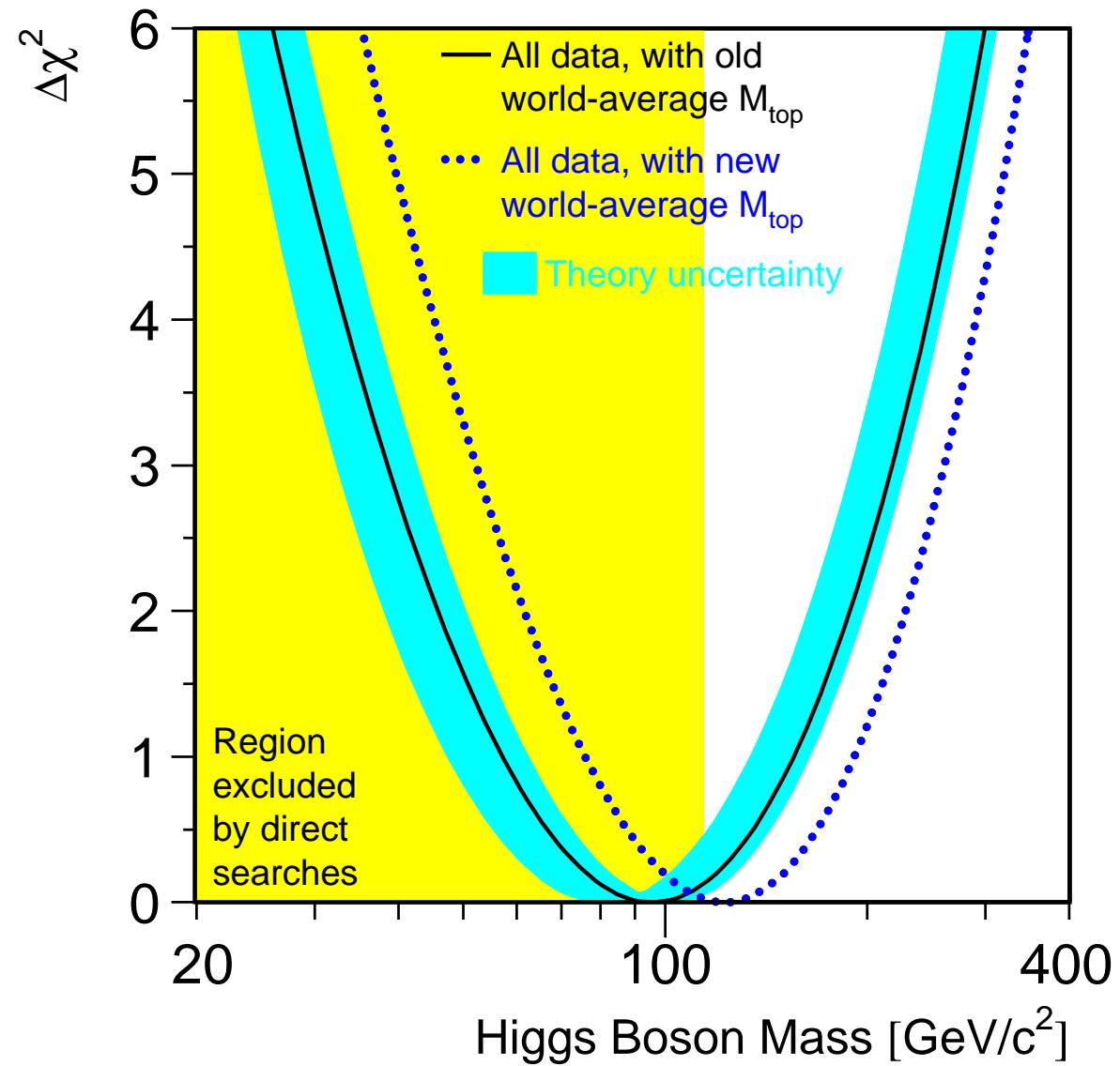
[LEPEWWG '04]

$$\Rightarrow M_H = 117^{+67}_{-45} \text{ GeV}$$

$$M_H < 251 \text{ GeV, 95\% C.L.}$$

Assumption for the fit:
SM incl. Higgs boson

→ no confirmation of
Higgs mechanism

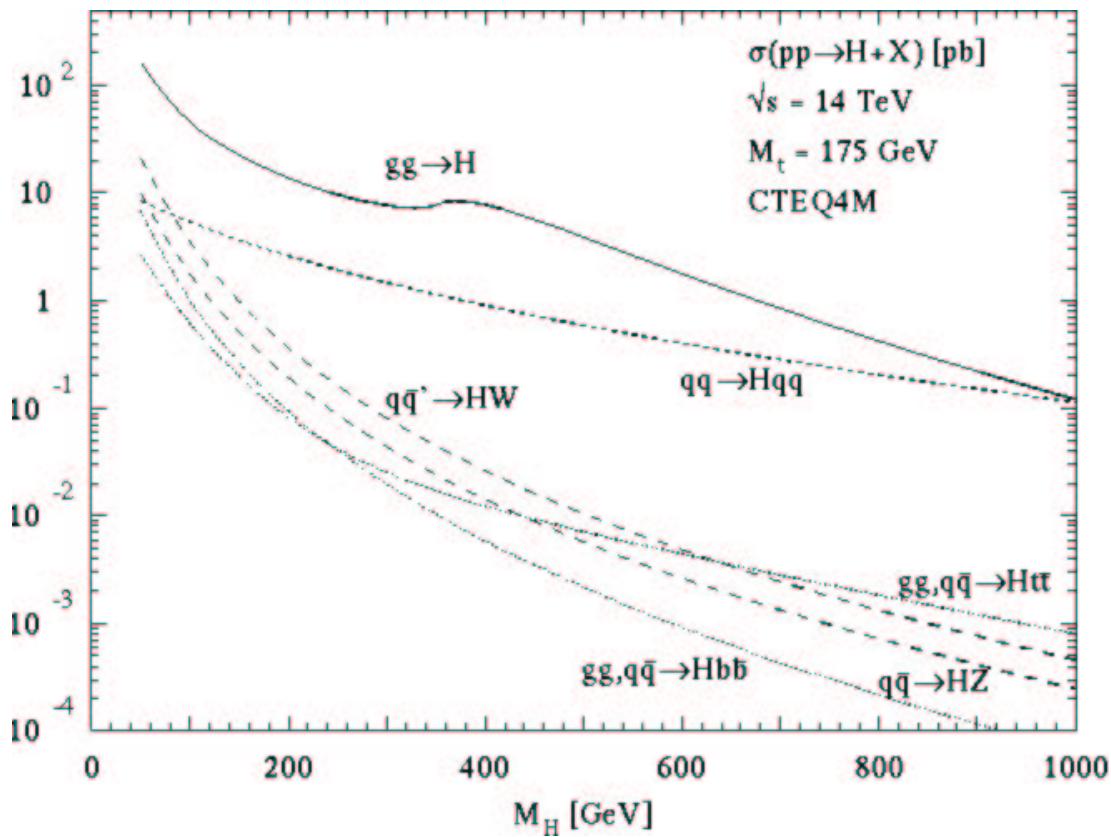


⇒ Higgs boson seems to be light, $M_H \lesssim 250 \text{ GeV}$

2. Higgs coupling determination at the LHC

[M. Dührssen, S.H., H. Logan, D. Rainwater, G. Weiglein, D. Zeppenfeld '04]

Higgs production at the LHC:



gluon fusion: $gg \rightarrow H$

weak boson fusion (WBF):
 $q\bar{q} \rightarrow q'\bar{q}'H$

top quark associated
production: $gg, q\bar{q} \rightarrow t\bar{t}H$

weak boson associated
production: $q\bar{q}' \rightarrow WH, ZH$

Some LHC specifics:

No LHC analogue to recoil method at LEP/LC: $e^+e^- \rightarrow ZH$, $Z \rightarrow e^+e^-$, $\mu^+\mu^-$

⇒ no total measurement of Higgs production cross section

QCD backgrounds ⇒ not all decay modes accessible, e.g. $H \rightarrow b\bar{b}$

Measurement of $\sigma \times \text{BR}$: narrow width approximation:

$$\Rightarrow \sigma(H) \times \text{BR}(H \rightarrow d_1d_2) = \frac{\sigma(H)^{\text{SM}}}{\Gamma_{\text{prod}}^{\text{SM}}} \times \frac{\Gamma_{\text{prod}} \Gamma_{\text{decay}}}{\Gamma_{\text{tot}}}$$

Observation of different channels (or upper bound from non-observation)

⇒ information on combinations of $\Gamma_b, \Gamma_\tau, \Gamma_W, \Gamma_Z, \Gamma_g, \Gamma_\gamma, Y_t^2$

⇒ Determination of ratios of partial width via global fit

[M. Dührssen '03]

⇒ Additional theoretical assumptions needed for absolute determination of partial widths

Example for theoretical assumptions:

[D. Zeppenfeld, R. Kinnunen, A. Nikitenko, E. Richter-Was '00]

- SM ratio of $\Gamma(H \rightarrow b\bar{b})/\Gamma(H \rightarrow \tau^+\tau^-)$
- SM ratio of $\Gamma(H \rightarrow WW^*)/\Gamma(H \rightarrow ZZ^*)$
- no large unexpected decay modes

⇒ determination of couplings, but ...

“SM in – SM out”?

⇒ questionable assumptions in many models (e.g. SUSY)

Q: Is it possible to measure couplings with “less” assumptions?

A: Yes! :-)

Strategy (I): very mild theoretical assumptions

- consider general multi-Higgs-doublet model
(w/o additional Higgs singlets)
(⇒ including e.g. MSSM)
- ⇒ HVV coupling bounded from above by SM value, $\Gamma_V \leq \Gamma_V^{\text{SM}}$, $V = W, Z$
- ⇒ upper bound on Γ_V

Observation of Higgs production

- ⇒ lower bound on production couplings
- lower bound on total width Γ_{tot}

Observation of $H \rightarrow VV^*$ in WBF

- ⇒ determines $\Gamma_V^2 / \Gamma_{\text{tot}}$
- ⇒ determines upper bound on Γ_{tot}

- ⇒ Absolute determination of Γ_{tot} and Higgs couplings via global fit
- ⇒ (nearly) model independent analysis

Strategy (II): more restrictive theoretical assumptions

→ consider more restrictive assumptions later

⇒ study possible improvements

Luminosity scenarios:

Three scenarios considered:

- $2 * 30 \text{ fb}^{-1}$: 30 fb^{-1} at each of the experiments
- $2 * 300 + 2 * 100 \text{ fb}^{-1}$: 300 fb^{-1} at each experiment, but only 100 fb^{-1} usable for WBF
(assume substantial degradation of WBF channel in high luminosity run)
- $2 * 300 \text{ fb}^{-1}$: 300 fb^{-1} at each experiment
(full luminosity usable for WBF channels)

Estimate of errors:

Statistical errors:

Assume **SM rates** for production and decay in each luminosity scenario

Systematic errors:

- 5% luminosity error
- uncertainties on reconstruction: identification of leptons: 2%
identification of photons: 2%
identification of b quarks: 3%
- forward tagging/veto jets: 5%
- error propagation for background determination from side-band analyses:
from 0.1% ($H \rightarrow \gamma\gamma$) to 5% ($H \rightarrow WW^*, H \rightarrow \tau^+\tau^-$)
- theoretical and parametric uncertainties for Higgs production:
 ggH : 20%, $t\bar{t}H$: 15%, WH, ZH : 7%, WBF: 4%
- theoretical and parametric uncertainties on Higgs decays:
1% (as a future expectation)

⇒ log likelihood function based on statistical and systematic errors

Decay channels considered:

- $H \rightarrow W^{+(*)}W^{-(*)} \rightarrow l^+l^- + p_{T,\text{miss}}$
- $H \rightarrow Z^{(*)}Z^{(*)}$
- $H \rightarrow \gamma\gamma$
- $H \rightarrow \tau^+\tau^-$
- $t\bar{t}H, H \rightarrow b\bar{b}$

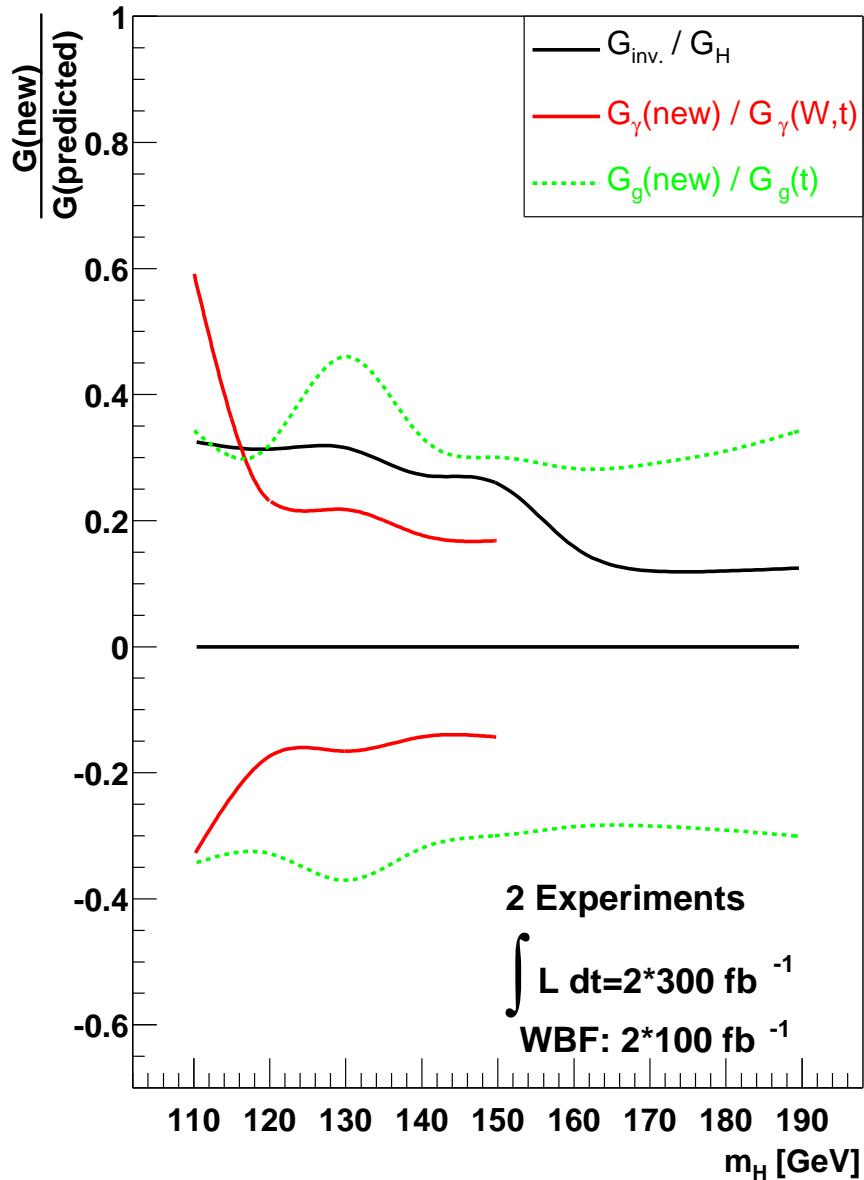
Strategy (I): assumptions (even less restrictive):

$$g_{HVV}^2 \leq 1.05 \times g_{HVV,\text{SM}}^2, \quad V = W, Z$$

5% margin to allow for

- theoretical uncertainties in translation of partial widths to g_{HVV}^2
- small admixtures of exotic states (triplets, ...)
- Allow for additional particles contributing to $H \rightarrow \gamma\gamma$ and $gg \rightarrow H$
(\Rightarrow fitted by pos. /neg. additional partial width to $H \rightarrow \gamma\gamma$ and $gg \rightarrow H$)
- Allow for additional Higgs decay width
(\Rightarrow fitted by additional partial width)

Constraints on extra partial widths:



Detection of SM rates
⇒ constraints on widths:

$2 * 300 + 2 * 100 \text{ fb}^{-1}$ scenario:

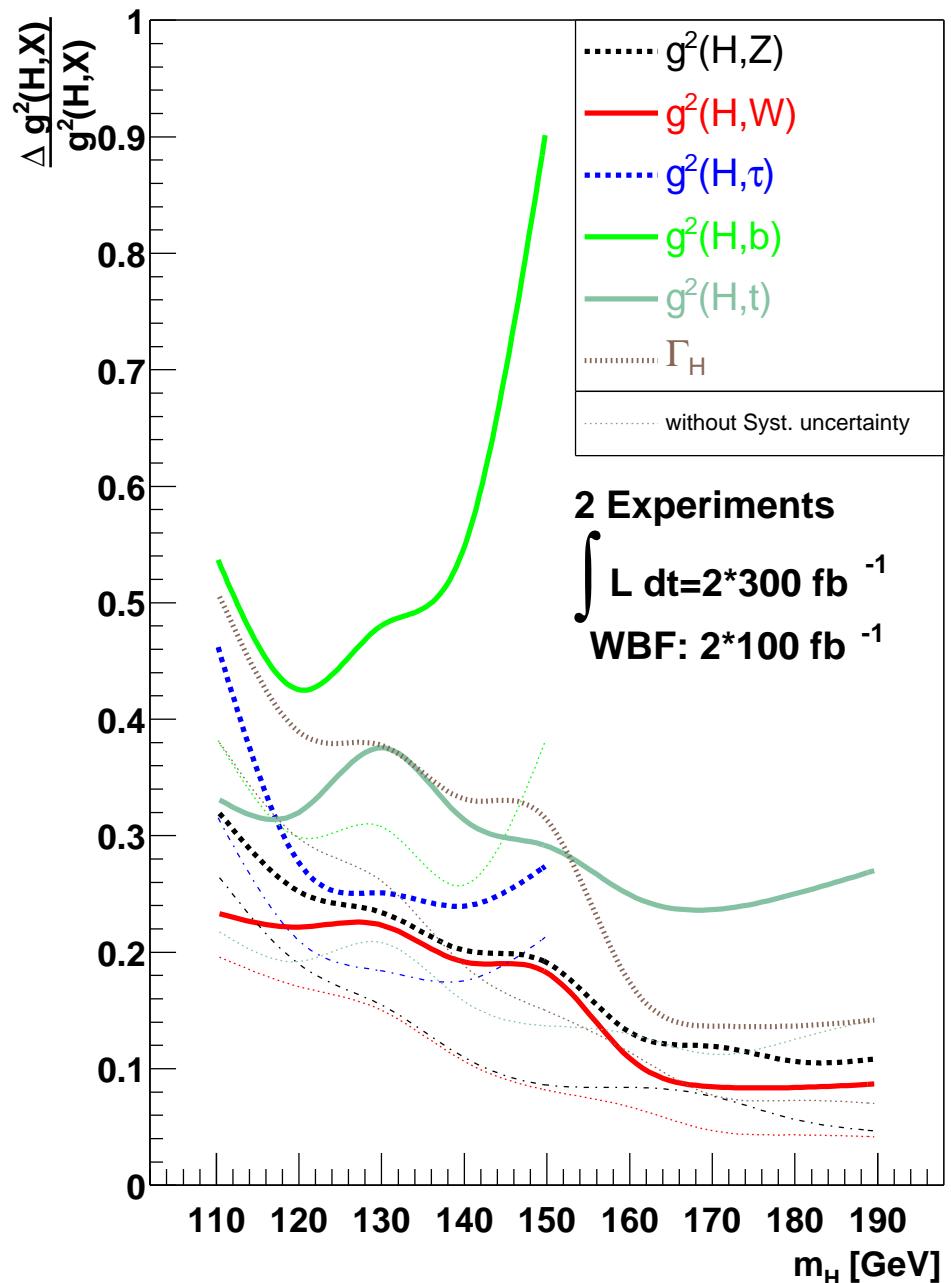
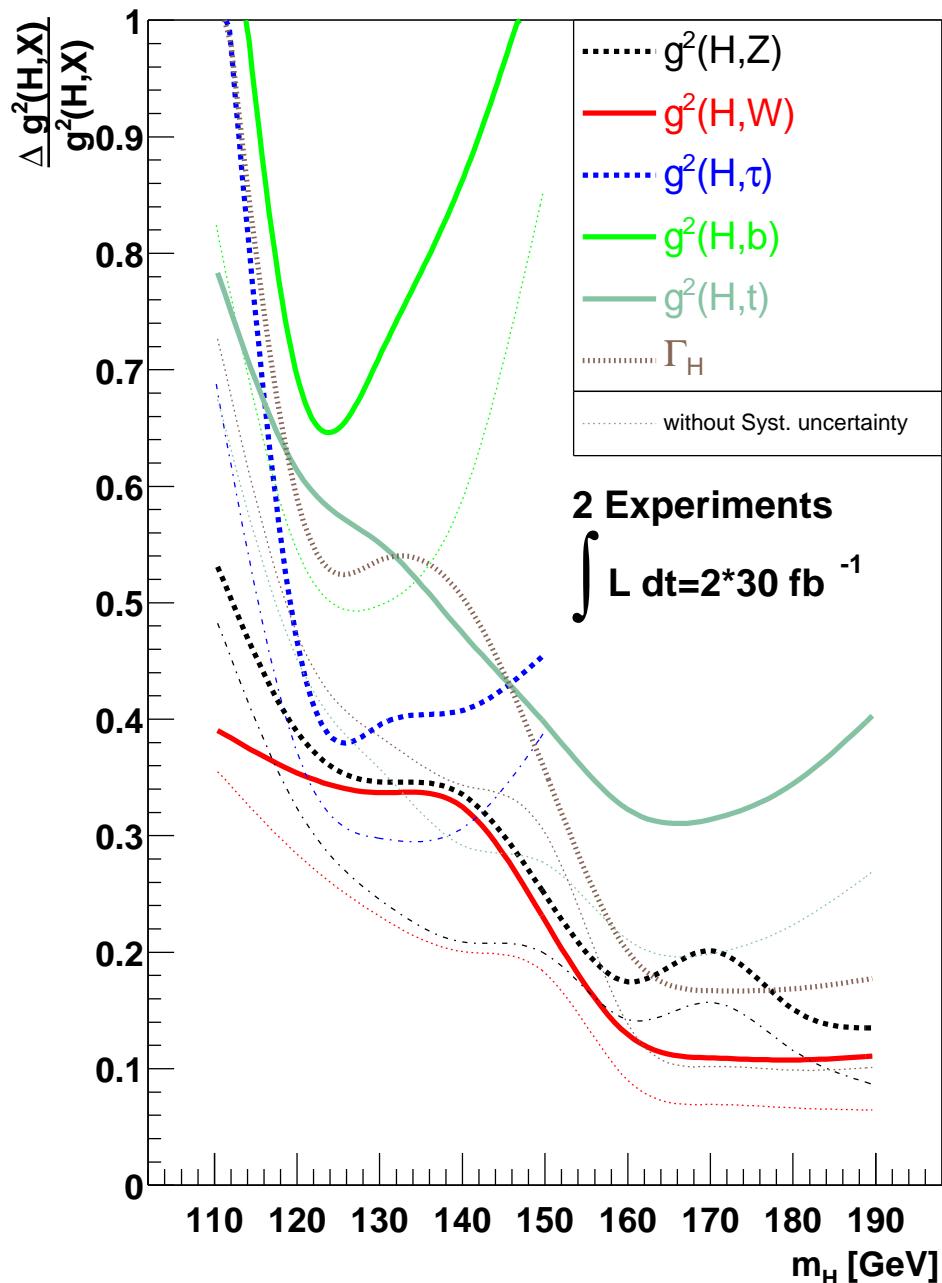
$$\Delta \Gamma_\gamma \leq 0.2 \times \Gamma_\gamma^{\text{SM}}$$

$$\Delta \Gamma_g \leq 0.4 \times \Gamma_g^{\text{SM}}$$

$$\Delta \Gamma_{\text{inv}} \leq 0.2 \times \Gamma_{\text{tot}}^{\text{SM}}$$

⇒ restrictions on new physics

Relative precisions for partial and total widths: two scenarios



Observations:

low luminosity scenario: $2 * 30 \text{ fb}^{-1}$:

for a light Higgs: results significantly worse as compared to higher luminosity scenario

high(er) luminosity scenario: $2 * 300 + 2 * 100 \text{ fb}^{-1}$:

- typical accuracies of $20\text{-}30\%$ for $m_H \leq 150 \text{ GeV}$
- 10% accuracies for HVV couplings above WW threshold

high luminosity scenario: $2 * 300 \text{ fb}^{-1}$:

significant improvement over $2 * 300 + 2 * 100 \text{ fb}^{-1}$ only in $H\tau\tau$ coupling
(WBF crucial for $H \rightarrow \tau^+\tau^-$)

Systematic errors contribute up to half of the total error, especially at high luminosity

Strategy (II): more restrictive assumptions:

additional assumption: HWW , HZZ couplings close to their SM values:

$$g_{HWW}^2 = g_{HWW,SM}^2 \pm 5\%, \quad g_{HZZ}^2 = g_{HZZ,SM}^2 \pm 5\%$$

→ realized e.g. in the MSSM for $M_A \gtrsim 200$ GeV (decoupling regime)

Further assumption (with small impact):

no new particles in loops of $H \rightarrow \gamma\gamma$ and $gg \rightarrow H$
(i.e. couplings fixed in terms of SM couplings and particles)

Additional Higgs decays still allowed

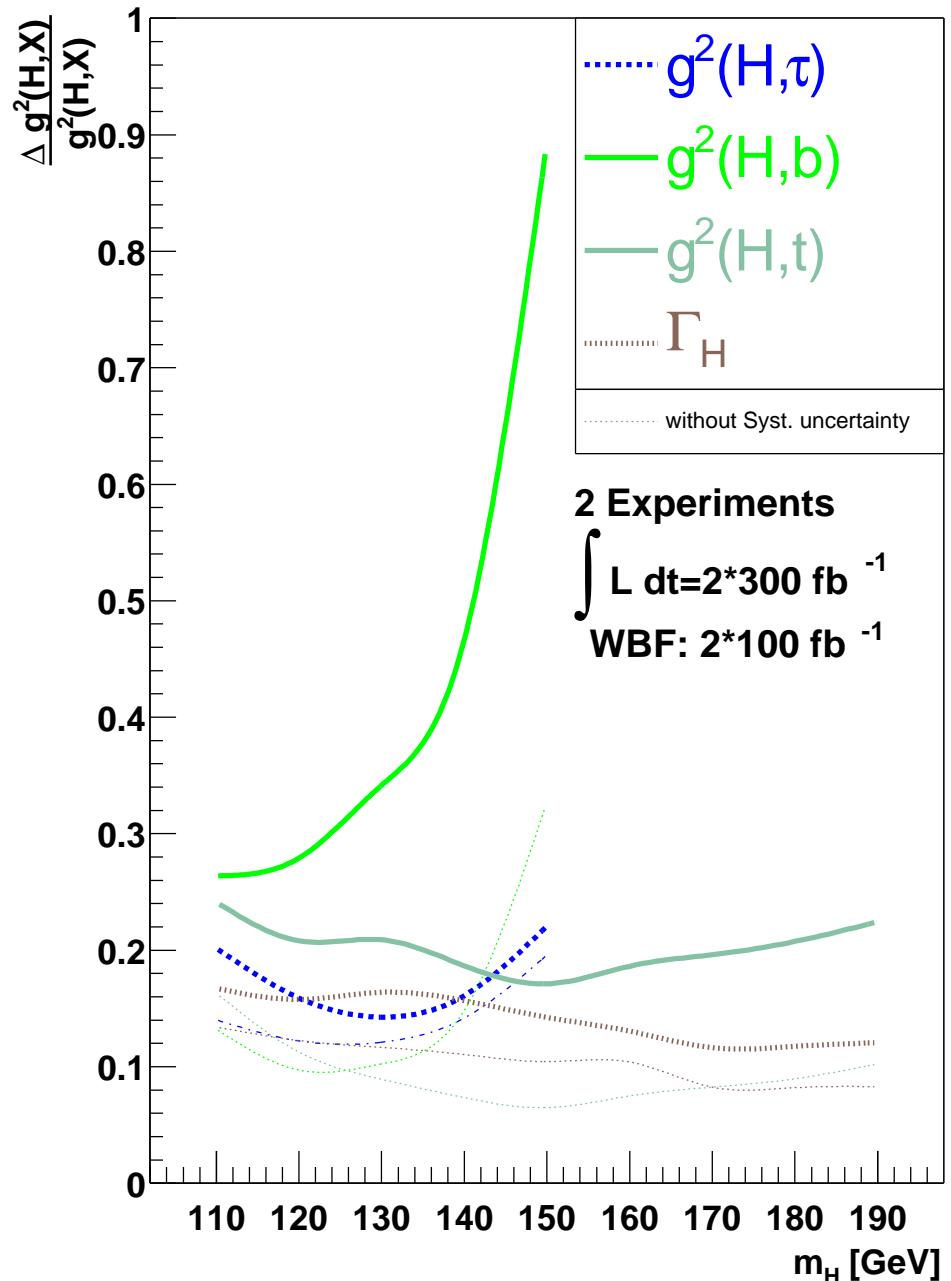
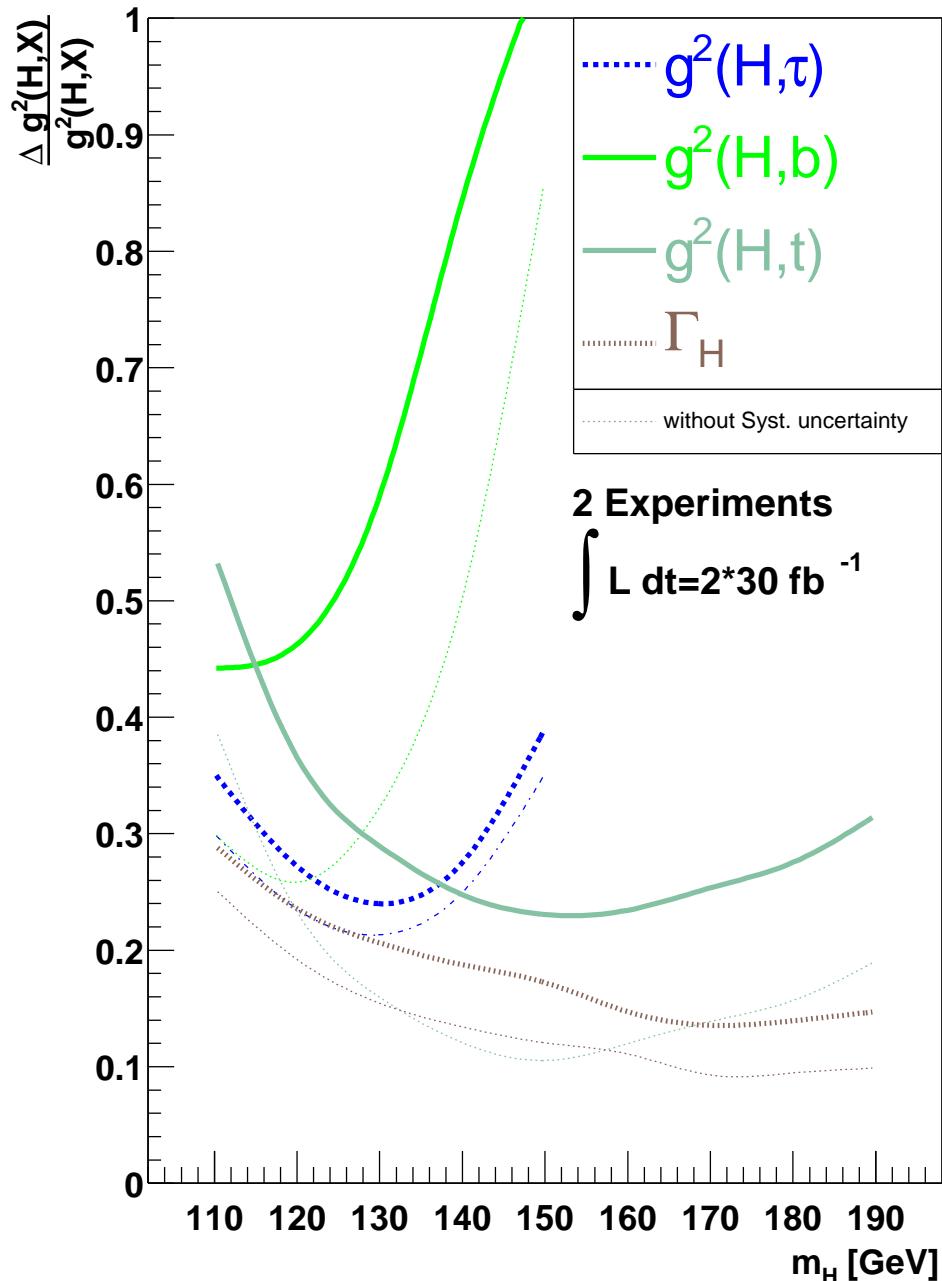
⇒ investigate improvements in width determination

→ T

⇒ drastic improvement in width determination

⇒ 10-20% precision in high luminosity scenario

Relative precisions for partial and total widths:

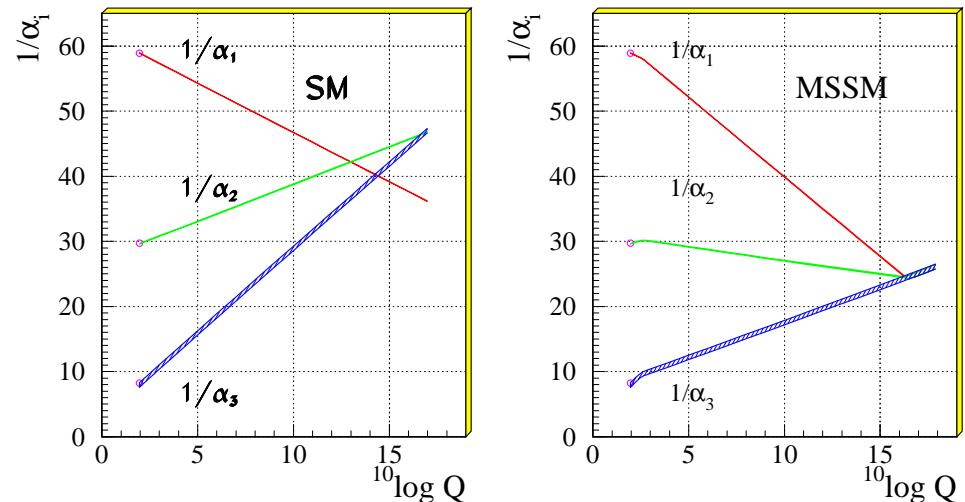


3. The heavy MSSM Higgs mass scale: indirect measurement

3A) Mini-Motivation: Nice features of the Supersymmetry

- Haag-Lopuszanski-Sohnius theorem
- local SUSY: connection to gravity
- coupling constant unification \Rightarrow
- Higgs mechanism for free \Rightarrow top quark mass prediction
- LSP is good CDM candidate

Unification of the Coupling Constants in the SM and the minimal MSSM



\Rightarrow The Minimal Supersymmetric Standard Model (MSSM) is a compelling candidate for physics beyond the SM

The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles

$[u, d, c, s, t, b]_{L,R}$	$[e, \mu, \tau]_{L,R}$	$[\nu_{e,\mu,\tau}]_L$	Spin $\frac{1}{2}$
$[\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}]_{L,R}$	$[\tilde{e}, \tilde{\mu}, \tilde{\tau}]_{L,R}$	$[\tilde{\nu}_{e,\mu,\tau}]_L$	Spin 0
g	$\underbrace{W^\pm, \textcolor{red}{H}^\pm}_{\textcolor{blue}{W^\pm, H^\pm}}$	$\underbrace{\gamma, Z, \textcolor{red}{H}_1^0, \textcolor{red}{H}_2^0}_{\textcolor{blue}{\gamma, Z, H_1^0, H_2^0}}$	Spin 1 / Spin 0
\tilde{g}	$\tilde{\chi}_{1,2}^\pm$	$\tilde{\chi}_{1,2,3,4}^0$	Spin $\frac{1}{2}$

Enlarged Higgs sector: Two Higgs doublets

Problem in the MSSM: many scales

Enlarged Higgs sector: Two Higgs doublets

$$H_1 = \begin{pmatrix} H_1^1 \\ H_1^2 \end{pmatrix} = \begin{pmatrix} v_1 + (\phi_1 + i\chi_1)/\sqrt{2} \\ \phi_1^- \end{pmatrix}$$

$$H_2 = \begin{pmatrix} H_2^1 \\ H_2^2 \end{pmatrix} = \begin{pmatrix} \phi_2^+ \\ v_2 + (\phi_2 + i\chi_2)/\sqrt{2} \end{pmatrix}$$

$$V = m_1^2 H_1 \bar{H}_1 + m_2^2 H_2 \bar{H}_2 - m_{12}^2 (\epsilon_{ab} H_1^a H_2^b + \text{h.c.})$$

$$+ \underbrace{\frac{g'^2 + g^2}{8}}_{\text{gauge couplings, in contrast to SM}} (H_1 \bar{H}_1 - H_2 \bar{H}_2)^2 + \underbrace{\frac{g^2}{2}}_{\text{gauge couplings, in contrast to SM}} |H_1 \bar{H}_2|^2$$

physical states: h^0, H^0, A^0, H^\pm

Goldstone bosons: G^0, G^\pm

Input parameters: (to be determined experimentally)

$$\tan \beta = \frac{v_2}{v_1}, \quad M_A^2 = -m_{12}^2 (\tan \beta + \cot \beta)$$

Contrary to the SM:

m_h is not a free parameter

MSSM tree-level bound: $m_h < M_Z$, excluded by LEP Higgs searches

Large radiative corrections:

Dominant one-loop corrections:

$$\Delta m_h^2 \sim G_\mu m_t^4 \ln \left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2} \right)$$

The MSSM Higgs sector is connected to all other sector via loop corrections
(especially to the scalar top sector)

Measurement of m_h , Higgs couplings \Rightarrow test of the theory

LC: $\Delta m_h \approx 0.05$ GeV

$\Rightarrow m_h$ will be (the best?) electroweak precision observable

Determination of the heavy Higgs boson mass scale M_A

LHC/LC reach for MSSM Higgs bosons:

LHC:

h : all $M_A - \tan \beta$ plane

H, A : unreachable parts

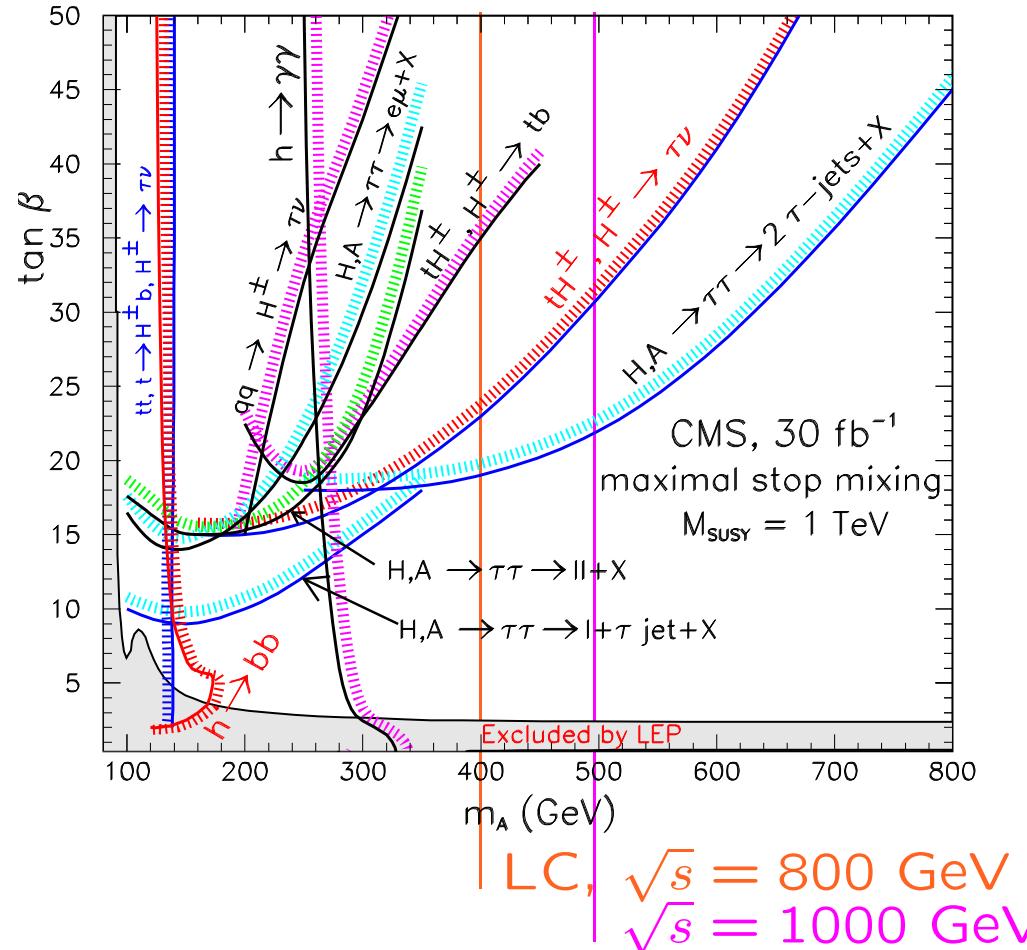
CMS, 30 fb^{-1} , m_h^{\max} scenario: \Rightarrow

LC:

kinematic limit: $M_A \lesssim \sqrt{s}/2 \rightarrow T$

$\rightarrow \sqrt{s} = 800 \text{ GeV}$

$\rightarrow \sqrt{s} = 1000 \text{ GeV}$

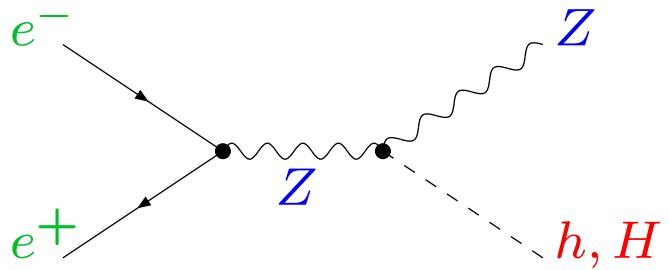


Q: Is it possible to extend the reach for heavy Higgs bosons ?

A: Yes, by direct and indirect measurements

Higgs production at the LC:

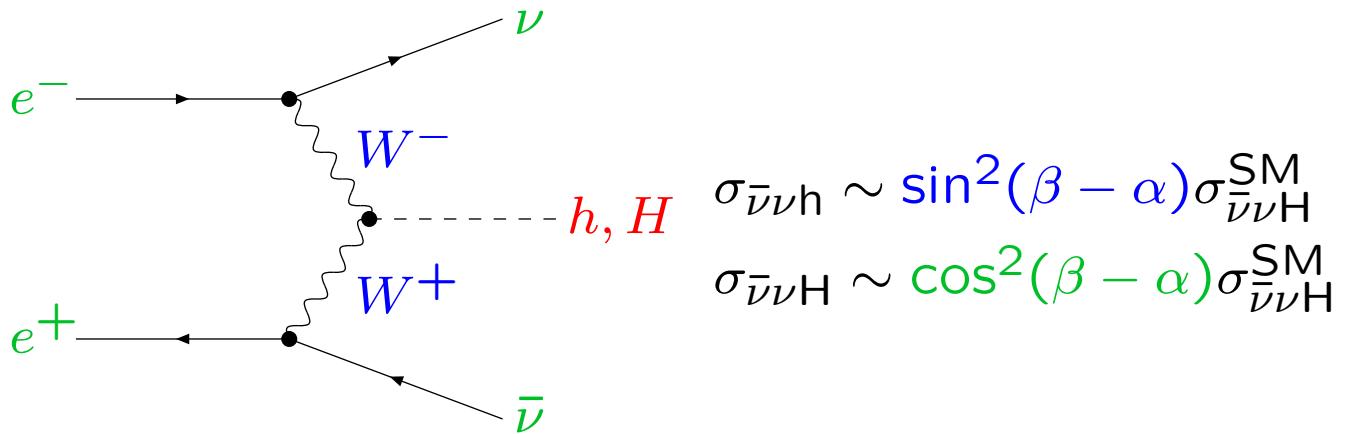
Higgs-strahlung process, $e^+e^- \rightarrow Zh, ZH$



$$\sigma_{hZ} \sim \sin^2(\beta - \alpha) \sigma_{HZ}^{\text{SM}}$$
$$\sigma_{HZ} \sim \cos^2(\beta - \alpha) \sigma_{HZ}^{\text{SM}}$$

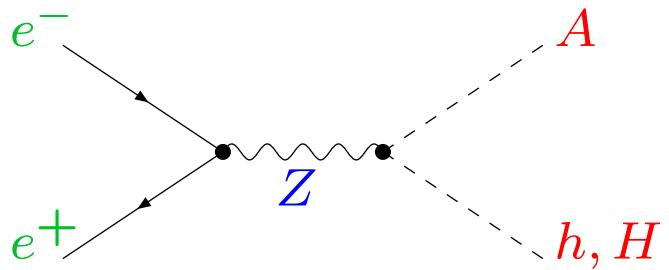
Dominates at low energies

Vector-boson fusion process, $e^+e^- \rightarrow \bar{\nu}_e \nu_e \{h, H\}$



Dominates at high energies

Higgs boson pair production, $e^+e^- \rightarrow Ah, AH$



$$\sigma_{hA} \sim \cos^2(\beta - \alpha) \sigma_{HZ}^{\text{SM}}$$
$$\sigma_{HA} \sim \sin^2(\beta - \alpha) \sigma_{HZ}^{\text{SM}}$$

Decoupling limit:

$M_A \gg M_Z$ (reached already for $M_A \gtrsim 200$ GeV)

$$\sin^2(\beta - \alpha) \rightarrow 1, \quad \cos^2(\beta - \alpha) \rightarrow 0, \quad M_H \approx M_A$$

⇒ h couples to vector bosons with SM strength

H decouples from vector bosons

production of heavy neutral Higgs bosons in e^+e^- mode only via HA pair production

kinematical limit: $M_H, M_A \lesssim \sqrt{s}/2$

3B) The heavy MSSM Higgs mass scale: indirect measurement

[*K. Desch, E. Gross, S.H., G. Weiglein, L. Zivkovic '04*]

Use all available information (**LHC** \oplus **LC**) to constrain M_A indirectly:

LHC: measurements of masses etc.

LC: mass measurements masses, mixing angles, BR's etc.

SPS1a scenario: prospective errors on masses and mixing angles known

LC measurement of

$$r \equiv \frac{[\text{BR}(h \rightarrow b\bar{b})/\text{BR}(h \rightarrow WW^*)]_{\text{MSSM}}}{[\text{BR}(h \rightarrow b\bar{b})/\text{BR}(h \rightarrow WW^*)]_{\text{SM}}}$$

gives sensitivity to M_A

Relevant precisions:

(all uncertainties are taken fully into account)

– $m_{\tilde{t}_1} \approx 400 \text{ GeV} \Rightarrow \delta m_{\tilde{t}_1} = 2 \text{ GeV}$
 $\Rightarrow \theta_{\tilde{t}} \text{ measurable}$

– $m_{\tilde{t}_2}$ not measurable at LHC/LC

– $\delta m_h^{\text{exp}} = 50 \text{ MeV}$

– $\delta m_h^{\text{theo}} \lesssim 0.5 \text{ GeV}$

\Rightarrow two bands allowed for $m_{\tilde{t}_2}$

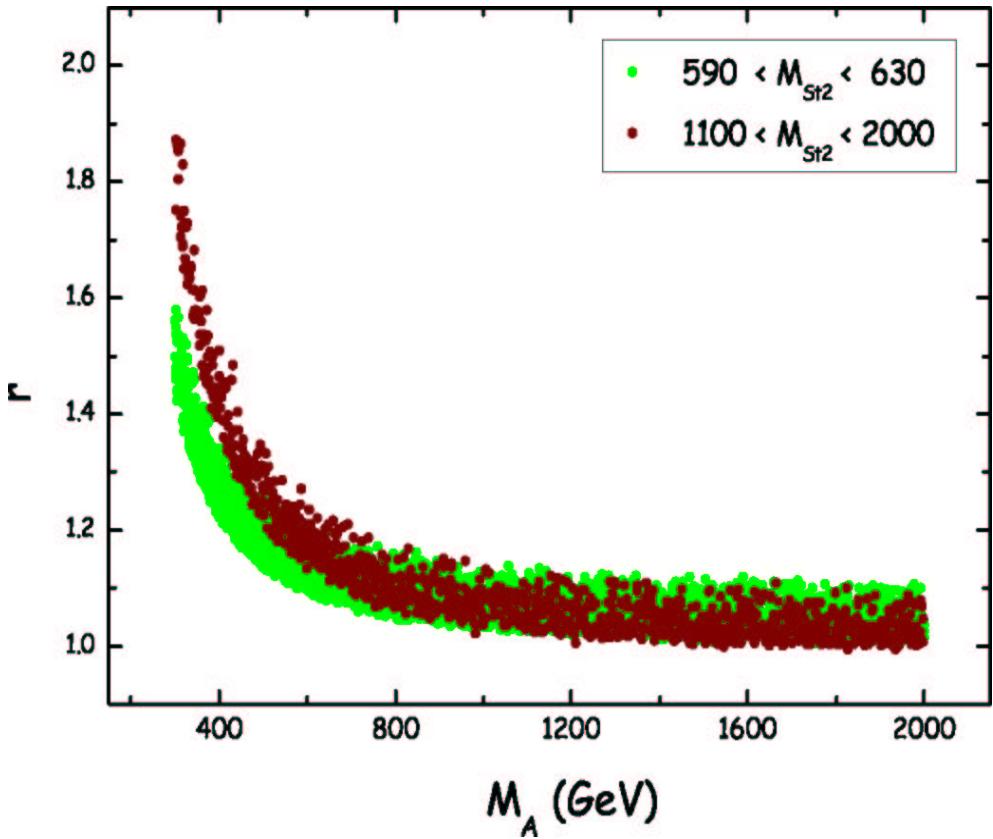
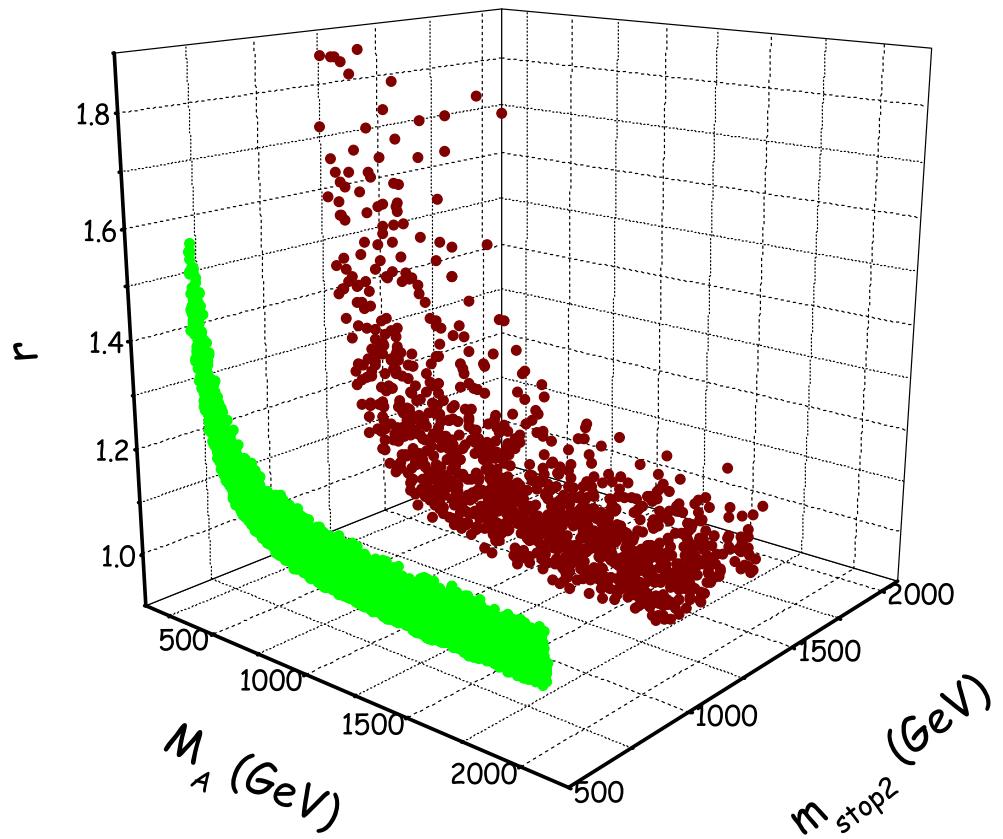
\Rightarrow investigate dependence of r on M_A

$\rightarrow T$

LC precision for r :

$\sqrt{s} \lesssim 500 \text{ GeV}: \Delta r/r = 4\% \quad [\text{TESLA TDR '01}]$

$\sqrt{s} \approx 1 \text{ TeV}: \Delta r/r = 1.5 \% \quad [\text{T. Barklow '03}]$

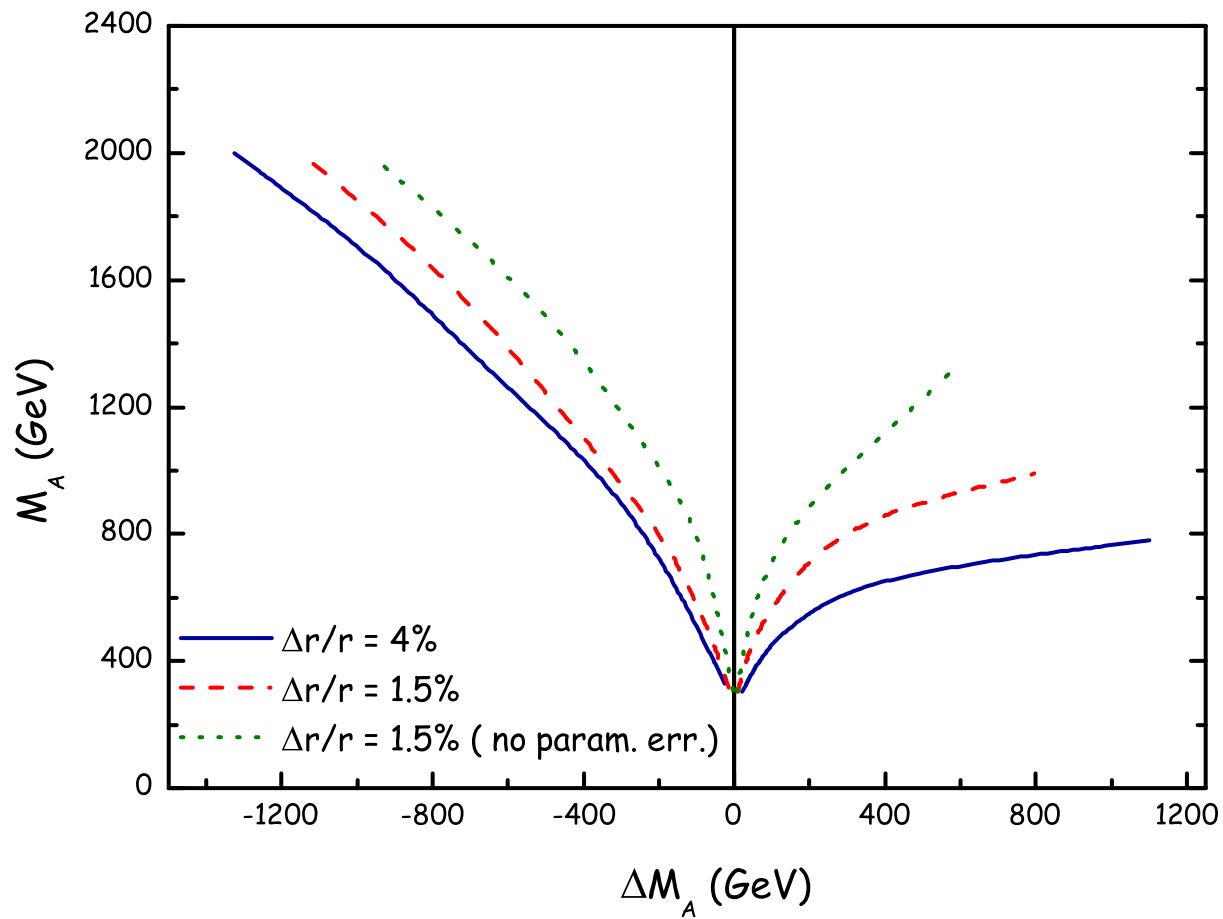


SPS1a: lower $m_{\tilde{t}2}$ band

→ distinction possible via $\theta_{\tilde{t}}$ measurement

variation in one band due to experimental/theoretical uncertainties

Apply experimental precision of r :



$\Delta r/r = 4\%$: upper limit on M_A up to $M_A \lesssim 800$ GeV

$\Delta r/r = 1.5\%$: $\Delta M_A/M_A = 20(30)\%$ for $M_A = 600(800)$ GeV

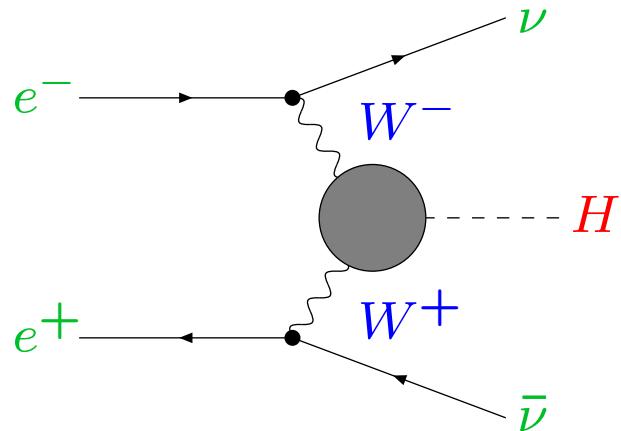
inclusion of parametric errors crucial for reliable bounds

4. The heavy MSSM Higgs mass scale: direct measurement

[T. Hahn, S.H., G. Weiglein '02]

WW fusion: $e^+e^- \rightarrow \bar{\nu}\nu H \sim \cos^2(\beta - \alpha) \Rightarrow$ decoupling

Loop corrections to VVH vertex could modify decoupling behavior:



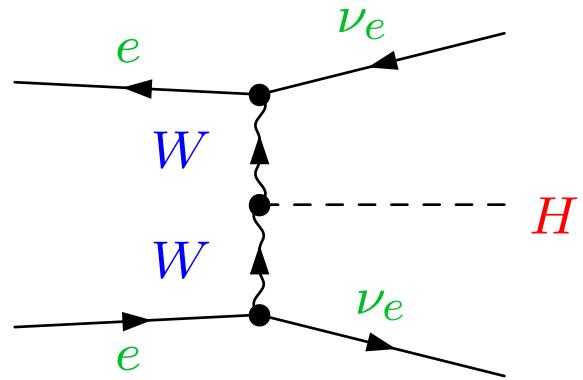
\Rightarrow Enhancement of LC reach into region $M_H > \sqrt{s}/2$?

Existing higher order calculations:

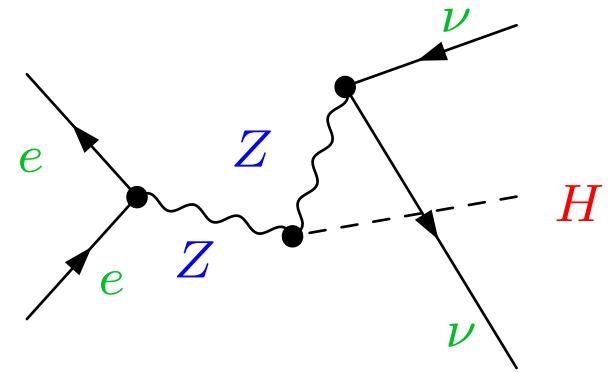
- $e^+e^- \rightarrow Zh, ZH$: large radiative corrections, up to two-loop
[S.H., W. Hollik, J. Rosiek, G. Weiglein '01]
- $e^+e^- \rightarrow Ah, AH$: large radiative corrections, up to two-loop
[S.H., W. Hollik, J. Rosiek, G. Weiglein '01]
- $e^+e^- \rightarrow \bar{\nu}\nu h, e^+e^- \rightarrow \bar{\nu}\nu H$ (with $M_H \sim M_Z$):
[H. Eberl, W. Majerotto, V. Spanos '02]
(3. family // α_{eff} for Higgs renormalization //
“inconvenient” renormalization scheme)
- $e^+e^- \rightarrow \bar{\nu}\nu A$: no WWA tree-level coupling, one-loop result tiny
[A. Arhrib '02]
- $e^+e^- \rightarrow \nu e^\mp H^\pm$:
no $W^\mp \{\gamma, Z\} H^\pm$ tree-level coupling, one-loop result tiny
[O. Brein, T. Hahn, S.H., G. Weiglein '04]
- $e^+e^- \rightarrow \bar{\nu}\nu H_{\text{SM}}$: full $\mathcal{O}(\alpha)$ corrections
[G. Belanger et al. '02] [A. Denner, S. Dittmaier, M. Roth, M. Weber '02]
[F. Jegerlehner, O. Tarasov '02]

Some details about the calculation:

Main process: WW fusion



same final state: Higgs-strahlung

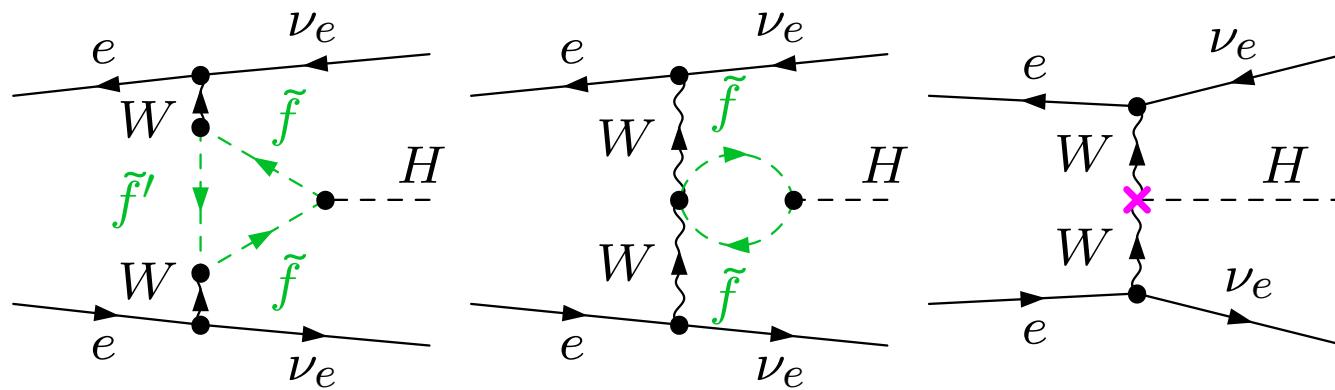
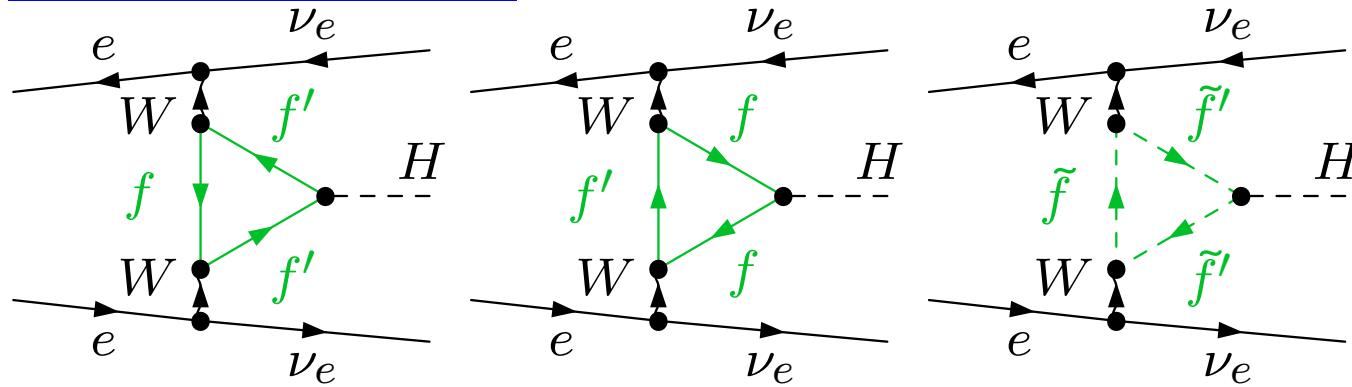


- ⇒ describe corrections to WW fusion
- ⇒ loop corrections to Higgs-strahlung taken into account in the same way

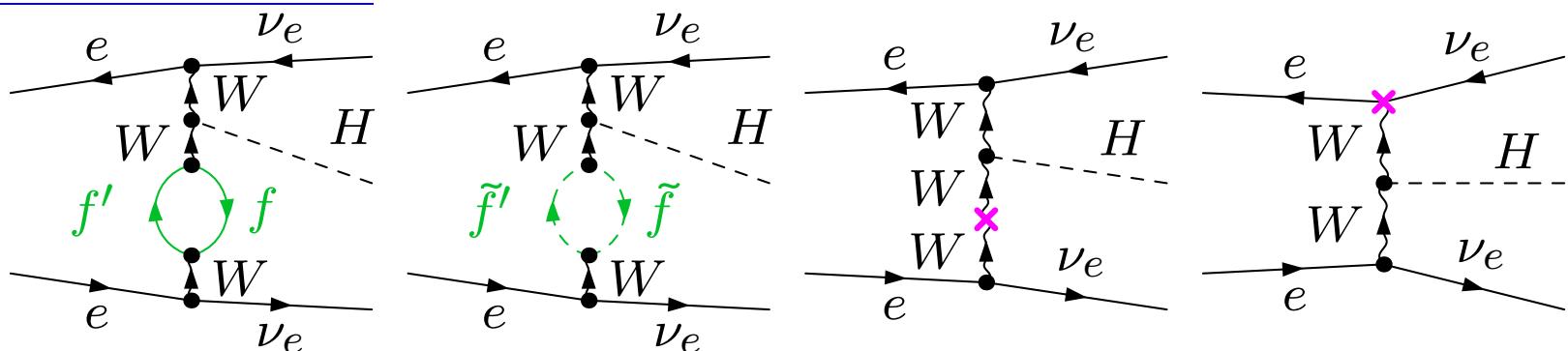
Included higher order corrections:

- ⇒ include all (s)fermion loops
- ⇒ sufficient for decoupling other corr. suppressed by $\cos^2(\beta - \alpha)$ (mostly)

Vertex corrections:



Further diagrams:



On-shell properties of outgoing Higgs boson:

→ finite wave function renormalization

$$\Gamma_{WWH}^{0,\text{WF}} = \sqrt{\hat{Z}_H} \left(\Gamma_{HWW}^{(0)} + \frac{1}{2} \hat{Z}_{hH} \Gamma_{hWW}^{(0)} \right)$$

\hat{Z}_h, \hat{Z}_H : finite residue of Higgs propagators

$\hat{Z}_{hH}, \hat{Z}_{Hh}$: finite Higgs mixing contribution

large Higgs propagator corrections enter \Rightarrow all available used \Rightarrow FeynHiggs

α_{eff} approx. \Rightarrow outgoing Higgs boson no longer on-shell

Cross section evaluation:

amplitude for $e^+e^- \rightarrow \nu_e \bar{\nu}_e H$: $\mathcal{M}_{H,e}^{(i)}$ ($i = 0, 1$)

WW fusion + Higgs-strahlung: tree-level (incl. WF corr.) + one-loop

amplitude for $e^+e^- \rightarrow \nu_f \bar{\nu}_f H$: $\mathcal{M}_{H,f}^{(0)}$ ($f = \mu, \tau$)

(experimentally indistinguishable final state)

$$\Rightarrow \sigma_H^1 \propto |\mathcal{M}_{H,e}^{(0)} + \mathcal{M}_{H,e}^{(1)}|^2 + |\mathcal{M}_{H,\mu}^{(0)}|^2 + |\mathcal{M}_{H,\tau}^{(0)}|^2$$

Numerical analysis for $e^+e^- \rightarrow \bar{\nu}\nu H$:

Assume $\sqrt{s} = 1$ TeV

⇒ investigate whether H can be produced beyond kinematical limit
for HA pair production

Optimistic (theorists') assumptions: integrated luminosity of $\mathcal{O}(2 \text{ ab}^{-1})$

⇒ $\sigma \approx 0.01 \text{ fb}$ taken as lower limit for observability (~ 20 events)

Discuss below results with and without beam polarization :

Idealized case: 100% pol. of both beams ⇒ enhancement by factor ≈ 4

More realistic case: 80% pol. of e^- beam, 60% pol. of e^+ beam

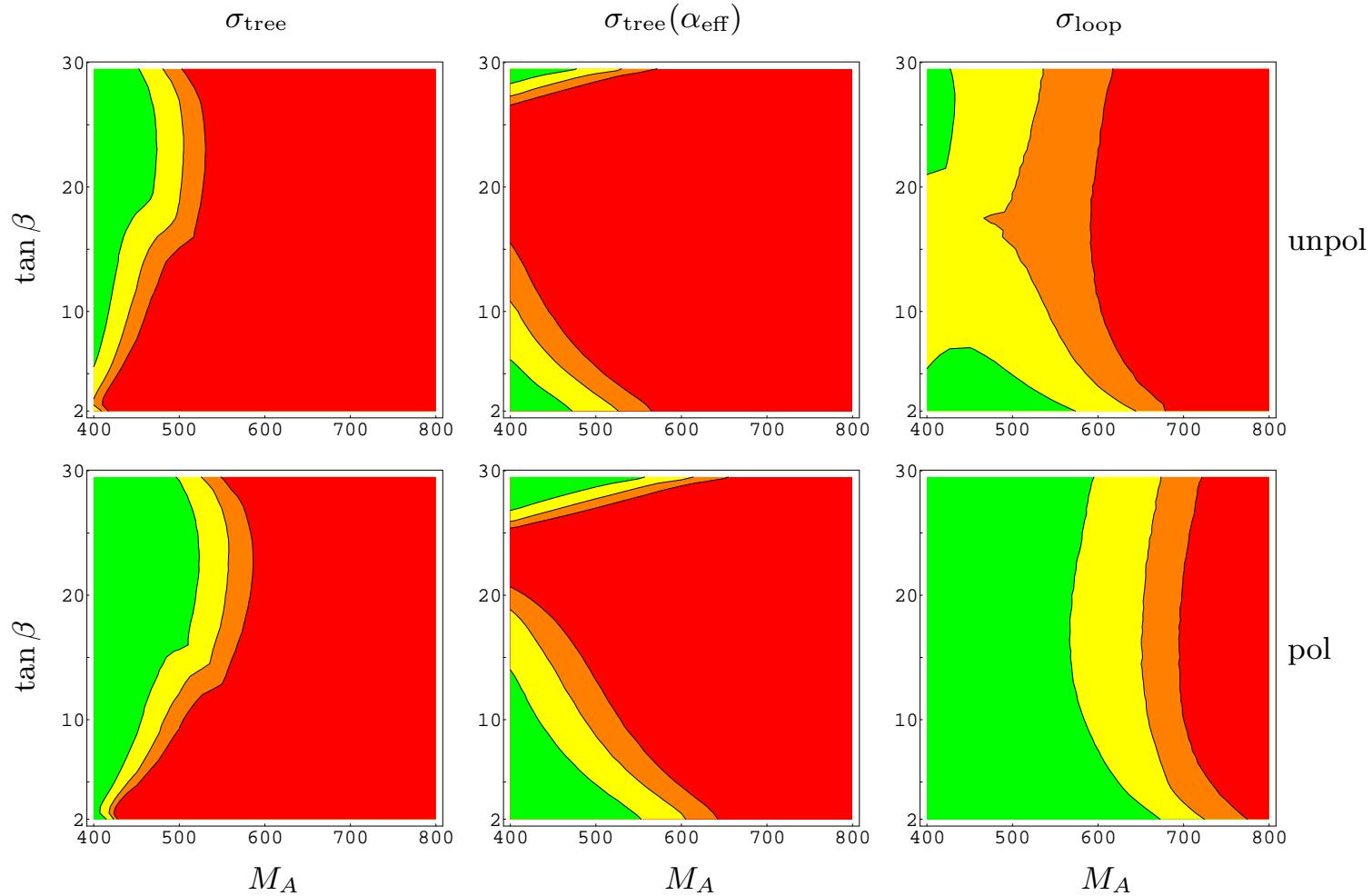
⇒ enhancement by factor ≈ 3

In examples below with beam polarization: idealized case assumed

Scenario: m_h^{\max} scenario, but $M_{\text{SUSY}} = 350 \text{ GeV}$, $\mu = 1000 \text{ GeV}$,

⇒ “ $m_h^{\max}(350/1000)$ ” scenario

Results in $m_h^{\max}(350/1000)$ scenario:



$\sigma_H < 0.01 \text{ fb}$
 $0.01 \text{ fb} < \sigma_H <$
 0.02 fb
 $0.02 \text{ fb} < \sigma_H <$
 0.05 fb
 $0.05 \text{ fb} < \sigma_H$

⇒ Large effects from genuine one-loop corr. and full wave function corr.

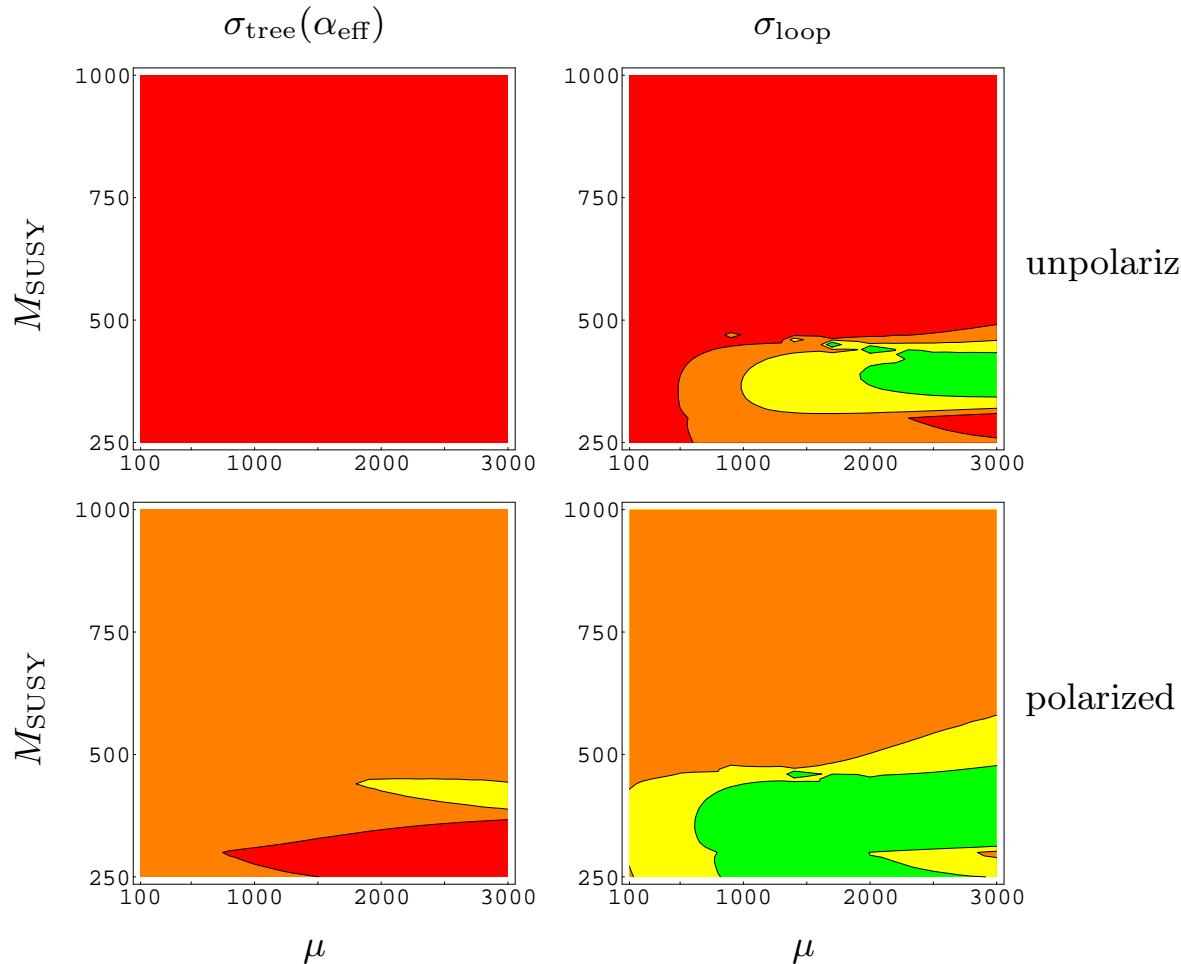
unpolarized case: H observation up to $M_A \lesssim 600 \text{ GeV}$ for all $\tan \beta$

polarized case: H observation up to $M_A = 700 - 750 \text{ GeV}$ for all $\tan \beta$

⇒ Enhancement of LC reach by more than 200 GeV

Enhancement happens over considerable regions of MSSM parameter space

m_h^{\max} scenario, $M_A = 600$ GeV, $\tan \beta = 4$, scan over μ , M_{SUSY}



Unpolarized case:

observation possible for
nearly all $M_{\text{SUSY}} \lesssim 500$ GeV
if $\mu \gtrsim 500$ GeV

Loop corrections very
important

Polarized case:

observation possible for all
scanned values of μ and
 M_{SUSY}

5. Conclusinos

- Higgs coupling determination at the LHC:

coupling determination necessary to establish the Higgs mechanism

→ (nearly) model independent analysis

⇒ coupling determination down to 20-40%

→ assume SM couplings for HWW , HZZ

⇒ coupling determination down to 10-20%

- Indirect heavy MSSM Higgs mass scale determination:

M_A is a crucial MSSM parameter, example: **SPS1a**

→ combine masses and mixing angles from LHC \oplus LC

→ take into account all experimental and theoretical uncertainties

→ measure $r \equiv \text{BR}(h \rightarrow b\bar{b})/\text{BR}(h \rightarrow WW^*)[\text{MSSM/SM}]$, $\Delta r/r \gtrsim 1.5\%$

⇒ M_A determination down to 20(30)% for $M_A = 600(800)$ GeV

- Direct heavy MSSM Higgs mass scale determination:

investigate channel $e^+e^- \rightarrow \nu\bar{\nu}H$ (in m_h^{\max} scenario)

→ loop corrections modify decoupling behavior

⇒ large enhancement of reach beyond $M_A \lesssim \sqrt{s}/2$ possible